Conservation and Field Management of the Freshwater Crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), in the Sydney Region, Australia

JOHN R. MERRICK

Graduate School of the Environment, Macquarie University, North Ryde NSW 2109

MERRICK, J.R. (1997). Conservation and field management of the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), in the Sydney region, Australia. *Proceedings of the Linnean Society of New South Wales* **118**, 217–225

Much of the natural range of *Euastacus spinifer*, in the Sydney region, is now included in the metropolitan and associated urban areas. Whilst a green belt of National Parks provides some reserves, these refuges are known to have been modified to varying degrees and many waterways outside Park boundaries are severely degraded.

Based on current biological knowledge of *E. spinifer* and experience with other *Euastacus* fisheries, a number of management options for this important macro-invertebrate are presented together with specific recommendations. Although effective conservation will require a number of interacting waterway and catchment programs, it is suggested that: recreational harvesting be restricted to the largest individuals (>85 mm CL) with small bag limits (5/person/day); a short annual closure (March-June) be declared; permanently closed areas be established with upgraded monitoring and response systems.

The ease of individual marking, sedentary behaviour, limited physiological tolerances, polytrophic status and longevity are all characteristics enhancing the potential of *E. spinifer* as a biological indicator. The types of catchment features, local habitat characteristics and biotic site data considered important for inclusion in quantitative habitat assessment for this crayfish, are briefly discussed.

Manuscript received 21 October 1996, accepted for publication 23 April 1997.

KEYWORDS: Management, conservation, freshwater crayfish, *Euastacus spinifer*, bio-monitor, habitat assessment.

INTRODUCTION

Conservation Status of Australian Crayfishes, Background

Some 33 Australian crayfishes have been reported as needing conservation attention (Horwitz 1995); of these, 14 are *Euastacus* species and one is found in New South Wales. Another, the Murray crayfish (*E. armatus*), is known to have undergone range reduction (Horwitz 1994; Versteegen and Lawler 1997). To date, recovery plans have not been developed for any of the threatened *Euastacus*.

The local situation relating to *Euastacus* in eastern New South Wales, was discussed by Merrick (1995), who also formulated general management recommendations; however, as much of its geographic range coincides with the extensive metropolitan area of Sydney as well as development surrounding the regional centres of Newcastle and Wollongong, the management of *Euastacus spinifer* needs urgent attention. A couple of observations about the exploitation of *Euastacus* are also relevant. Honan and Mitchell (1995) considered that another large species, *E. bispinosus*, with a similar life history could not sustain even moderate mortality rates. When discussing three large Victorian *Euastacus* species, Horwitz (1990) reported that the range of each had declined and implicated fishing pressure.

Fortunately, the acknowledgement of the need for integrative management of whole catchments has been accompanied by detailed studies relevant to local *E. spinifer* habitats. These include: research on soil erosion by Hannam (1995) in steep forested catchments; studies on parts of the Hawkesbury-Nepean System in relation to diversity of riparian vegetation (Benson 1995), its rehabilitation (Benson and Howell 1993), riparian vegetation corridors (Outhet et al. 1995) and their interactions with the waterway (Brooks 1995). Swales (1994) also discussed in-stream flows for fauna in N.S.W. rivers.

Management Options

The broad, commonly accepted management objectives (maintenance of resource sustainablility, maintenance of satisfactory recreation for users), expressed by Barker (1990) for other freshwater fisheries, also apply to *E. spinifer*. But, as Horwitz (1994) points out, effective protection cannot be achieved without adequate policing and intensive education of recreational users.

With recently published biological data (Turvey and Merrick 1997a,b,c,d,e) the potential now exists to define optimal environmental parameters and incorporate *Euastacus spinifer* management into local environmental plans. Furthermore this crayfish, among aquatic macro-invertebrates in the Sydney region, has good potential for long-term bio-monitoring.

Bio-monitoring

The use of biota to assess water quality and optimal criteria for selecting indicator species, as well as ways of assessing or rating impacts are questions still subject to much controversy; the situation in Australia is summarised by Bunn (1995). Bio-monitoring has been approached in a number of ways, using a wide variety of organisms (Norris and Norris 1995); however, several general conclusions can be drawn from experience. These are: that, whilst macro-invertebrates have been the most popular group, different key or indicator species (from widely disparate taxa) are probably necessary in different areas (Wright 1995); that many of the initial indices developed, based solely on biodiversity, have limited value (Norris and Norris 1995); that the most robust predictive systems now being developed involve a suite of contributing environmental and biotic characters (Harris 1995); that, using identified early warning features (such as enzyme change), the future predictive capacity of these models needs to be developed (Bunn 1995; Holdway et al. 1995); that interactive links must now be developed between assessment or monitoring models and field management.

Objectives of this paper are: to summarise biological and environmental baseline data into a series of major management criteria; to discuss management options, in relation to key biological cycles or previous experience with other *Euastacus* species and suggest specific interim measures; to explain the unusual features that make *E. spinifer* particularly suitable as a long-term biological indicator; and to outline types of data that should be incorporated in a quantitative predictive assessment model.

REVIEW AND DISCUSSION

Baseline Data, Life Cycle Strategy

Environmental and biological data, together with population observations, from previous studies are summarised under three major categories of requirements or management phases (Table 1). These criteria form the basis of a number of recommendations as options for any monitoring or conservation program.

Euastacus spinifer has a long-term, low mortality life cycle strategy which depends on individuals reproducing annually for many years (Turvey and Merrick 1997a). A unique feature of some *E. spinifer* populations is the presence of a significant percentage of very small but sexually mature males (Morgan 1997), designated as precocious males (Turvey and Merrick 1997a). The origins and benefits of this group remain unclear but there is evidence that the frequency of small size classes, may be related to the numbers of aquatic predators (Merrick 1995; Turvey and Merrick 1997b). A relatively sedentary nature makes *Euastacus* species susceptible to local predation (which includes over-fishing).

TABLE 1

Selected baseline data listed as major management criteria (summarised from Turvey and Merrick 1997a, b, c, d, e).

Feature	Range/Comment
ENVIRONMENTAL PREFERENCES	
Substrate	Sand or gravel, logs and some rock; decomposing terrestrial detritus (≥0.5 kg/m^2); some steep banks shaded by overhanging natural vegetation.
Macrophytes	Small beds of ribbon weed.
Water Conditions*	Low turbidity, salinity, temps (9–25°C), D.O. >6.0 p.p.m.
BEHAVIOUR PATTERNS, LIFE CYCLE	
Feeding, Mating	Peak activity at night — especially early evening (sunset to moonrise). Juveniles eat same foods as adults. Mating — Autumn (temps ↓15°C)
Non-migratory, Territorial	No dispersal phase, details unknown but home ranges small
Growth and Longevity+	Growth declines with age, males mature at ≥5 years (45–55mm CL), females at ≥8 years (~70mm CL). Individuals may survive for 20–40 years
KEY ANNUAL BIOLOGICAL PHASES	
Moulting†	Throughout warmer months in juveniles; seasonal peaks (Autumn, Spring) in medium-sized sub-adults; summer in large males and large females in Autumn (temps 22–15°C).
Reproduction‡	Spawning — Early Winter (at 10–11°C) Incubation (110–140 days) Larval attachment (28–70 days) in Spring to Early Summer. Juvenile release — Early Summer (20–24°C).

* Water parameters obviously vary (e.g. turbidity increases with flushes or flooding) but these fluctuations are short-term.

+ Populations appear to support small numbers of large adults.

† Moulting frequency varies with age and is influenced by a number of factors, but most maturing and mature individuals moult at the times stated.

‡ The exact timing of the reproductive cycle may vary in different river systems.

As was found with *E. bispinosus*, environmental modification has probably led to reduction and fragmentation of *E. spinifer* populations; furthermore, Honan and Mitchell (1995) point out that local population sizes of *E. bispinosus* are relatively small. Many *E. spinifer* habitats are also small and only appear to support relatively small numbers of adults, which have a patchy distribution (Turvey and Merrick 1997b). This type of situation can pose special management difficulties in the maintenance of genetic heterogeneity.

Management Options

The Victorian and south-western New South Wales *Euastacus* fisheries have had closures (4–7 years) to allow for assessment and collection of baseline data (Barker 1990). *E. spinifer* fisheries have not been closed, although some of the discussion below draws on the findings of those closure studies mentioned above. As Table 2 indicates, restoring the aquatic system has two major aspects, the watercourse and bank areas. Stream bed restoration, in turn, involves maximising area of aquatic environment (by re-activating natural meandering reaches or subsidiary channels) and increasing diversity of habitats (with respect to features such as flow, substrate or cover). For example, to ensure adequate food and shelter in areas where a watercourse has been de-snagged, some logs or other woody debris should be replaced or allowed to accumulate. Programs for the complete reconstruction and rehabilitation of highly modified urban streams in western Sydney are currently in progress (Schaffer and Maelzer 1996).

Maintenance or establishment of small ribbon-weed beds has two direct benefits for *E. spinifer*. They provide potential cover, especially for juveniles, and macrophytes selectively extract metals and other compounds from water passing over them. So these plants act as in-stream filters. Another way of maintaining optimal water quality, especially high dissolved oxygen (DO) levels, is to increase or stimulate prolonged in-stream flow. This may be achieved in several ways: (a) negotiation with the managing authority of an upstream impoundment for increased releases; (b) restrictions on quantities of water that can be drawn or diverted from the stream; (c) modification or removal of an upstream impoundment structure that is no longer essential for catchment activities.

The importance of intact riparian zones, both for supplying energy and maintaining water quality, has been well documented (Bunn 1986). It has been reported that riparian zones are particularly badly effected by urbanisation (Adam 1995). Over much of the *E. spinifer* range natural riparian vegetation would comprise eucalypt sclerophyll forest or woodland with pockets of rainforest in sheltered situations (Australian Surveying and Land Information Group 1990; McLoughlin 1985); techniques for restoring these floristic complexes have been well developed (Friederich 1991).

The existing regulations relating to the New South Wales *E. armatus* fishery (NSW Fisheries 1994) are a useful framework on which local management can be based; but several specific modifications are necessary. The suggested minimum size (85–90mm) is high, both in relation to normal maturation sizes and maximum lengths attained by the species (Turvey and Merrick 1997a, e). The recommended bag limit is low in comparison with the catch limits set for *E. bispinosus*, which were apparently not effective. If tight controls are imposed initially, in the interests of sharing a limited resource, any subsequent relaxation would generate a positive user response. While the concept of uniform state-wide catch regulations is logical, with 24 *Euastacus* species of widely differing sizes and restricted distributions (Morgan 1997), it is not practical.

In Victorian fisheries *Euastacus* species can only be trapped during the breeding and brooding period, at other times of the year adults are inactive and inaccessible, so breeding season closures are unworkable (Barker 1990). This natural cessation of cray activity does not occur with *E. spinifer* and it can be caught at most times of the year. What is proposed is a short closed season coinciding with the peak moulting and mating activity of harvestable adults. Although researchers have previously suggested removing closures for other *Euastacus* fisheries (Barker 1990), it is strongly recommended that some closed areas be retained for *E. spinifer*. There are several reasons for this: the documented regional variability in the species; the continued existence of large populations only in areas with limited public access and little urban impact; reduction of potential problems in areas difficult to monitor. This type of strategy was also suggested for the giant Tasmanian freshwater crayfish, *Astacopsis gouldi*, which is widespread with a similar life cycle and subject to the same types of threatening processes and exploitation. Horwitz (1994) proposed adequate reservation by measures such as restricting fishing in National Parks or Forestry reserves.

To take advantage of the nocturnal activity cycle all sampling would be best done in the early evening; however, aside from initial surveys to gather local or populational baseline data, subsequent handling should be minimal to alleviate any risks of physiological stress. As individuals remain in limited areas for long periods of time, mark-recapture projects are recommended; the animals are easily marked (Merrick 1993; Turvey and Merrick 1997b) or externally tagged. Monitoring programs of this kind have already commenced with several Victorian *Euastacus* species (Barker 1992).

Whilst remembering that as many populations should be conserved as possible, to retain genetic heterogeneity (Versteegen and Lawler 1997), the recovery phase for *E. spinifer* may be a long-term process. In areas where populations have been dramatically reduced, or where local extinctions have occurred, culturing and repeated stocking may be necessary for periods of 8–10 years. This will allow for the slow individual growth and sexual maturity and enable natural recruitment to become significant. Techniques for culturing *Euastacus* species are summarised in Merrick (1997).

It may also be necessary to actively control other large carnivorous species in the system. Significant numbers of predators such as eels, cod, cormorants or water rats would negate the benefits of cray stocking or other riparian restorative measures (Barlow and Bock 1984; Sokol 1988). Control could involve culling or regulation of in-stream migrations.

Despite the active involvement of many community groups (such as bush regenerators, anglers, students, naturalists, scouts or youth clubs) in different aspects of management the effectiveness of any initiatives will ultimately depend on comprehensive patrolling. This is unfortunately essential because the areas of concern are accessible and adjacent to large human populations; there is a constant threat of illegal activity (e.g. dumping, arson) or pollution accidents. Whilst many factors can and will impact on these urban or semi-rural *E. spinifer* habitats the author considers the major threats to be fire, chemical pollution and introduced species.

There are two important aspects of fire management that relate to riparian zones. Wet sclerophyll and rainforest communities are particularly badly effected by fire, as they are less resilient in regenerating than other drier communities (Friend 1996). Then, although fire control regimes are still subject to much controversy, it is clear that rapid containment is essential otherwise the intensity of the blaze quickly builds to uncontrollable levels (Adams and Simmons 1996; Incoll 1996).

There are several considerations relating to chemical pollution. The waterways concerned are small (in size, volume, flow rates) and so have limited capacity to buffer or dilute the impacts of intermittent spills or continued small releases. At least some pollutants would lodge in the substrates or sediment and persist in the system, possibly for long periods after release of the toxins was stopped. Details of exact sites are not readily available, but it is known that Sydney and associated long-established areas have a number of pollution 'hot spots'; these pose longstanding and on-going environmental management problems.

A summary of the main pollutants, sources and effects on water quality in local urban waterways is included in Essery (1995). Although some data are available on toxicities and system interactions of a few major industrial pollutants (Chapman 1995), the effects of many other compounds (such as synthetic hormones or related derivatives) have not been considered locally, but problems caused by these substances have been identified elsewhere (Jobling and Sumpter 1993; Jobling et al. 1996).

Introduced species (exotic or non-indigenous forms) pose two major biotic threats; the first is ecological disruption and or direct competition for limited resources, the second is disease. The problems of introductions and translocations of aquatic organisms have been well documented (Courtenay 1990; Horwitz 1995) and need not be repeated here, but the potential for disease transmission is more insidious. Unfortunately recent research on aquatic diseases indicates that many groups of parasitic micro-organisms can utilise a variety of hosts, transferring from one group to another depending on circumstances (Semple 1995).

It is emphasised that while the detailed, field-oriented suggestions (Table 2) relate specifically to identified local problems, they should be considered in conjunction with broader conservation management initiatives (Merrick 1995).

TABLE 2

Summary of specific management recommendations for *Euastacus spinifer* (based on Barker 1990; Honan and Mitchell 1995; Merrick 1993, 1995; Turvey and Merrick 1997a, b, c, d, e).

1. Initiate research programs on:
   - (a) detailed nutritional requirements;
   - (b) interactions with *Cherax destructor*;
   - (c) the relationship of predation by eels to population structure and recruitment;
   - (d) tolerances to major chemical pollutants identified in waterways of range.

2. Restore aquatic habitat by:
   - (a) allowing woody debris to accumulate in watercourse, re-establishing selected macrophytes;
   - (b) restoration and protection of riparian zones.

3. Improve water quality by:
   - (a) identifying and removing sources of pollution;
   - (b) modifying structures impeding water flow and aquatic faunal movement (*).

4. Convert the *E. spinifer* fishery to a sport category with strict regulations, including:
   - i a high minimum size (e.g. 85–90mm CL);
   - ii only males to be retained when catches approach bag limit (e.g. 5 person/day);
   - iii berried females to be released immediately;
   - iv bans on trapping from mid-March to mid-June (peak moulting, mating period);
   - v permanent exclusion zones (closed waters) or refuges in less accessible areas.

5. Establish comprehensive field monitoring and an effective patrolling organisation (with appropriate legal powers) for long-term management.

(*) Maintaining a minimal environmental flow will be critical during severe conditions, such as drought.

Bio-monitoring

A wide range of aquatic organisms have been suggested as bio-indicators of waterway health (Cullen 1990) but, aside from its ecological importance in local fluviatile systems, *E. spinifer* has several special features which make it particularly suitable as a key indicator species in the long-term in the Sydney region.

With relatively narrow tolerances for oxygen and temperature this cray would be sensitive to organic pollution with a high oxygen demand; it would also react to thermal pollution. As a result of its polytrophic role *E. spinifer* is also exposed to accumulated pollutants at all major levels of the aquatic food chain. This large invertebrate is easy to monitor in a confined area, so population disruptions would be a sensitive indicator of point source problems. Furthermore, the work on *E. bispinosus,* indicates that it cannot sustain any significant pressure or mortality. Finally, the longevity of *E. spinifer* makes it an ideal subject for bio-accumulation studies and assessment of sublethal or chronic impacts.

Habitat Assessment Model

Recent fishery management forums and studies have logically placed a high priority on habitat (Cadwallader 1993; Hancock 1993; Lawrence 1991); but the emphasis has been on fishes and their requirements, which do not necessarily coincide with optimal conditions for invertebrates. Chessman (1995) developed an assessment method for macro-invertebrates in the Sydney region but, although useful, this system needs further refinement by inclusion of more environmental factors that are important for crayfishes.

Chessman's assessment is based on standardised collection of a range of aquatic invertebrates from up to six defined stream habitats; a biotic index is then calculated on the basis of sensitivities of taxa (at family level) to common pollutants. The disadvantages of this model, in relation to *E. spinifer*, include the acknowledged interspecific variation in tolerance to particular types of pollutants and potential errors in occurrence ratings, with a favourable small habitat only supporting a small number of large individuals. Although substrates are considered indirectly, cover and food availability (amounts of litter) are not included. Neither flow nor depth, factors known to significantly affect abundance in crayfishes, are considered in detail and levels of natural predation are not assessed. Finally, the states of immediate riparian zones are not included.

Perhaps these parameters could be incorporated in the development of a general regional bioassessment system based on an Index of Biotic Integrity or IBI (Harris 1995) or the River Invertebrate Prediction and Classification System (RIVPACS) concept (Wright 1995). Fortunately the Sydney region is now sufficiently documented (Chessman 1995; Growns et al. 1995) that much of the required reference data would be available.

Although *E. spinifer* is now considered one of the more widespread *Euastacus* species (Morgan 1997) the total natural range also coincides with the most densely populated and highly developed coastal areas in the state. In this instance, there is no alternative to more active management, to upgrade monitoring and protection in existing reserves and to maintain environmental quality in other areas. Opportunities for creating additional reserves in this highly developed region are very limited. So successful conservation programs developed for crayfishes around Sydney will be useful in local sustainable environmental management in many other areas. As Horwitz (1995) points out most fisheries and environmental protection legislation in Australia now contains sections that require relevant authorities to control processes which degrade water quality, so theoretically, many of the threatening processes are controllable; however, for remedial measures to be invoked locally the species has to be recognised as threatened and in need of regulatory protection

ACKNOWLEDGMENTS

Appreciation is expressed to Paul Turvey (Maianbar, New South Wales) for discussion and comments on this manuscript, which is partially based on earlier biological studies of *E. spinifer*. I would also thank Miss P. R. Davies, Graduate School of the Environment, Macquarie University for assistance with manuscript preparation.

REFERENCES

Adam, P. (1995). Urbanization and transport. In 'Conserving biodiversity: threats and solutions'. (Eds R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen) pp. 55–75. (Surrey Beatty & Sons Ltd., Chipping Norton).

Adams, R. and Simmons, D. (1996). The impact of fire intensity on litter loads and understorey floristics in an urban fringe dry sclerophyll forest and implications for management. In 'Fire and biodiversity. The effects and effectiveness of fire management. Proceedings of the Conference held 8–9 October 1994, Footscray, Melbourne'. pp. 21–35. (Department of the Environment, Sport and Territories, Canberra).

Australian Surveying and Land Information Group. (1990). 'Atlas of Australian resources. Third series. Volume 6. Vegetation'. (Australian Government Publishing Service, Canberra).

Barker, J. (1990). Spiny freshwater crayfish management strategy. *Fisheries Management Report* (34), 1–17. *Department of Conservation & Environment, Melbourne.*

Barker, J. (1992). The spiny freshwater crayfish monitoring program, 1990. *Fisheries Management Report* (44), 1–31. *Department of Conservation & Environment, Melbourne.*

Barlow, C.G. and Bock, K. (1984). Predation of fish in farm dams by cormorants, *Phalacrocorax* spp. *Australian Wildlife Research* **11**, 559–566.

Benson, D. (1995). Vegetation interactions with rivers: plant biodiversity associated with riparian and flood-plain corridors. In 'Geomorphology and river health in New South Wales'. (Eds G.J. Brierley and F. Nagel) pp. 81–84. (Graduate School of the Environment, Macquarie University).

Benson, D.H. and Howell, J. (1993). 'A strategy for the rehabilitation of the riparian vegetation of the Hawkesbury-Nepean River'. (Royal Botanic Gardens, Sydney).

Brooks, A. (1995). Vegetative interaction with rivers: morphodynamic associations - implication for river health. In 'Geomorphology and river health in New South Wales'. (Eds G.J. Brierley and F. Nagel) pp. 49–66. (Graduate School of the Environment, Macquarie University).

Bunn, S.E. (1986). Origin and fate of organic matter in Australian upland streams. In 'Limnology in Australia'. (Eds P. De Deckker and W.D. Williams) pp. 277–291. (CSIRO/Junk,Melbourne).

Bunn, S.E. (1995). Biological monitoring of water quality in Australia: workshop summary and future directions. *Australian Journal of Ecology*, **20** (1), 220–227.

Cadwallader, P.L. (ed). (1993). 'Freshwater fisheries in Victoria - today and tomorrow. Symposium Proceedings, Radisson President Hotel, Queens Road, Melbourne, 11 October 1992'. (Department of Conservation and Natural Resources, Victoria).

Chapman, J.C. (1995). The role of ecotoxicity testing in assessing water quality. *Australian Journal of Ecology* **20** (1), 20–27.

Chessman, B. (1995). Rapid assessment of rivers using macroinvertebrates: a procedure based on habitat - specific sampling, family level identification and a biotic index. *Australian Journal of Ecology* **20** (1), 122–129.

Courtenay, W.R. Jnr. (1990). Fish introductions and translocations and their impacts in Australia. In 'Introduced and translocated fishes and their ecological effects'. (Ed D. A. Pollard) pp. 171–179. (Australian Society for Fish Biology Workshop, Bureau of Rural Resources Proceeding 8).

Cullen, P. (1990). Biomonitoring and environmental management. *Environmental Monitoring and Assessment* **14**, 107–114.

Essery, C. (1995). Geomorphology and water quality. In 'Geomorphology and river health in New South Wales.' (Eds G.J. Brierley and F. Nagel) pp. 131–136. (Graduate School of the Environment, Macquarie University).

Friederich, R. (1991). Management of rainforest in national parks and equivalent reserves in northern New South Wales. In 'The rainforest legacy. Australian National Rainforests Study. Volume 3'. (Eds G. Werren and P. Kershaw) pp. 216–230.(Australian Heritage Commission, Special Australian Heritage Publication Series 7).

Friend, G. (1996). Fire ecology of invertebrates - implications for nature conservation, fire management and future research. In 'Fire and biodiversity. The effects and effectiveness of fire management. Proceedings of the Conference held 8–9 October 1994, Footscray, Melbourne'. pp. 155–162. (Department of the Environment, Sport and Territories, Canberra).

Growns, J.E., Chessman, B.C., McEvoy, P.K. and Wright, I.A. (1995). Rapid assessment of rivers using macroinvertebrates: case studies in the Nepean River and Blue Mountains, NSW. *Australian Journal of Ecology* **20** (1), 130–141.

Hancock, D.A. (ed). (1993). 'Sustainable fisheries through sustaining fish habitat. Australian Society for Fish Biology Workshop, Victor Harbor, SA, 12–13 August 1992'. (Bureau of Resource Sciences Proceedings, AGPS, Canberra).

Hannam, I. (1995). Soil conservation in steep forested catchments in New South Wales. In 'Geomorphology and river health in New South Wales'. (Eds G.J. Brierley and F. Nagel) pp. 31–39. (Graduate School of the Environment, Macquarie University).

Harris, J.H. (1995). The use of fish in ecological assessments. *Australian Journal of Ecology* **20** (1), 65–80.

Holdway, D.A., Brennan, S.E. and Ahokas, J.T. (1995). Short review of selected fish biomarkers of xenobiotic exposure with an example using fish hepatic mixed-function oxidase. *Australian Journal of Ecology* **20** (2), 34–44.

Honan, J.A. and Mitchell, B.D. (1995). Catch characteristics of the large freshwater crayfish, *Euastacus bispinosus* Clark (Decapoda: Parastacidae), and implications for management. *Freshwater Crayfish* **10**, 57–69.

Horwitz, P. (1990). The conservation status of Australian freshwater crustacea. *Australian National Parks and Wildlife Service Report Series* (14), 1–121.

Horwitz, P. (1994). Distribution and conservation status of the Tasmanian giant freshwater lobster *Astacopsis gouldi* (Decapoda: Parastacidae). *Biological Conservation* **69**, 199–206.

Horwitz, P. (1995). The conservation status of Australian freshwater crayfish: review and update. *Freshwater Crayfish* **10**, 70–80.

Incoll, R. (1996). Asset protection in a fire prone environment. In 'Fire and biodiversity. The effects and effectiveness of fire management. Proceedings of the Conference held 8–9 October 1994, Footscray, Melbourne'. pp. 213–217. (Department of the Environment, Sport and Territories, Canberra).

Jobling, S., Sheahan, D., Osborne, J.A., Matthiesen, P. and Sumpter, J.P. (1996). Inhibition of testicular growth in rainbow trout (*Oncorhynchus mykiss*) exposed to estrogenic alkylphenolic chemicals. *Environmental Toxicology and Chemistry* **15** (2), 194–202.

Jobling, S. and Sumpter, J.P. (1993). Detergent components in sewage effluent are weakly oestrogenic to fish: an in vitro study using rainbow trout (*Oncorhynchus mykiss*) hepatocytes. *Aquatic Toxicology* **27**, 361–372.

Lawrence, B.W. (1991). 'Fish management plan'. (Murray-Darling Basin Commission, Canberra).

McLoughlin, L. (1985). The middle Lane Cove River. A history and a future. *Centre for Environmental and Urban Studies (Macquarie University), Monograph* (1), 1–175.

Merrick J.R. (1993). 'Freshwater crayfishes of New South Wales'. (Linnean Society of New South Wales, Sydney).

Merrick, J.R. (1995). Diversity, distribution and conservation of freshwater crayfishes in the eastern highlands of New South Wales. *Proceedings of the Linnean Society of New South Wales* **115**, 247–258.

Merrick, J.R. (1997). 'Freshwater fish and cray farming in Australia'. (J.R. Merrick Publications, Sydney).

Morgan, G.J. (1997). Freshwater crayfish of the genus *Euastacus* Clark (Decapoda: Parastacidae) from New South Wales, with a key to all species of the genus. *Records of the Australian Museum, Supplement* (23), 1–110.

Norris, R.H. and Norris, K.R. (1995). The need for biological assessment of water quality: Australian perspective. *Australian Journal of Ecology* **20** (1), 1–6.

NSW Fisheries. (1994). Fisheries Management Act 1994 - Regulation. (Fisheries Management (General) Regulation 1994). (New South Wales Government, Sydney).

Outhet, D., Duckham, J., Stewart, D., Ardill, S. and Holics, M. (1995). Riverine corridor vegetation-Nepean River and tributaries - Wollondilly Local Government Area. In 'Geomorphology and river health in New South Wales'. (Eds G.J. Brierley and F. Nagel) pp. 67–79. (Graduate School of the Environment, Macquarie University).

Schaffer, B. and Maelzer, B. (1996). 'Restoring the waters project'. (Australian Conservation Foundation, Sydney).

Semple, G.P. (1995). Occurrence of pathogenic *Thelohania* (Microsporida: Nosematidae) in the Australian freshwater crayfish, *Cherax quadricarinatus* (Decapoda: Parastacidae). *Proceedings of the Linnean Society of New South Wales* **115**, 225–231.

Sokol, A. (1988). The Australian yabby. In 'Freshwater crayfish: biology, management and exploitation'. (Eds D.M. Holdich and R.S. Lowery) pp. 401–425. (Croom Helm Ltd., London).

Swales, S. (1994). Streamflow requirements for fish in NSW rivers - the role and importance of flushing flows. In 'Proceedings of the environmental flows Seminar, Canberra 25–26 August 1994'. pp. 178–183. (Australian Water and Wastewater Association, Sydney).

Turvey, P. and Merrick, J.R. (1997a). Reproductive biology of the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), from the Sydney region, Australia. *This volume.*

Turvey, P. and Merrick, J.R. (1997b). Population structure of the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), from the Sydney region, Australia. *This volume.*

Turvey, P. and Merrick, J.R. (1997c). Diet and feeding in the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), from the Sydney region, Australia. *This volume.*

Turvey, P. and Merrick, J.R. (1997d). Moult increments and frequency in the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), from the Sydney region, Australia. *This volume.*

Turvey, P. and Merrick, J.R. (1997e). Growth with age in the freshwater crayfish, *Euastacus spinifer* (Decapoda: Parastacidae), from the Sydney region, Australia. *This volume.*

Versteegen, M. and Lawler, S. (1997). Population genetics of the Murray River crayfish *Euastacus armatus*. *Freshwater Crayfish* **11**, (in press).

Wright, J.F. (1995). Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology* **20** (1), 181–197.